Bis Ring Closing Olefin Metathesis for the Synthesis of Unsaturated Polycyclic Ethers. O-Membered Ring Cyclization in Favor of C-Membered Ring Cyclization

Christophe Baylon,[†] Marie-Pierre Heck,[†,‡] and Charles Mioskowski*[,†,§,||]

CEA, CE-Saclay, Service des Molécules Marquées, Bât 547, Département de Biologie Cellulaire et Moléculaire, 91191 Gif Sur Yvette, France, and Laboratoire de Synthèse Bio-Organique associé au CNRS, Faculté de Pharmacie, Université Louis Pasteur, 74 route du Rhin BP 24, 67401 Illkirch, France

Received October 19, 1998

Introduction

Since first being reported more than thirty years ago,[1] the metathesis of olefins to produce carbon−carbon double bonds has been of great synthetic interest, notable for ring opening metathesis polymerization (ROMP).[2] In recent years this metal-catalyzed exchange of alkylidene groups has been further studied resulting in the development of new catalysts, mainly by Osborn (tungsten),[3] Schrock (tungsten and molybdenum),[4] and Grubbs (ruthenium).[5] These metals exhibit high metathesis activity and stability toward functional groups, and since their discovery, many reports have been published on the subject of ring closing metathesis (RCM) for the formation of relatively strained cycloalkenes,[6] substituted cyclic olefins,[7] O- or N-containing heterocycles,[8] and macrocycles.[9] More recently, some selective olefin cross-metatheses[10] have been introduced as well as solid-phase ring closing metathesis reactions.[11] To date, many total syntheses of natural products have employed a metathesis key step.[12]

While the use of ring closing metathesis for the synthesis of unsaturated oxygen and nitrogen heterocycles,[4−8] phospholenes and cyclic phosphonates,[13] cyclic silyloxy olefins,[14] and thiophenes[15] is fully documented, these methods are generally limited to a single cyclization step

[†] CEA.

[‡] Phone: +33(0)169086352. e-mail: heck@dsvidf.cea.fr. Fax: +33-(0)169087991.

[§] Université Louis Pasteur.

[||] Phone: +33(0)388676863. e-mail: mioskow@bioorga.u-strasbg.fr. Fax: +33(0)388678891.

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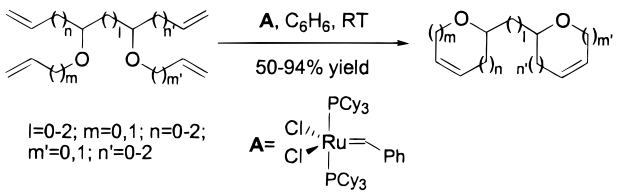
10.1021/jo982098u CCC: $18.00
Published on Web 04/02/1999

Scheme 1. Catalytic RCM of Tetraenes



leading to an unsaturated mono-heterocycle. Note, while there is literature precedent for the preparation of bicyclic compounds,[16] these transformations involved either a two-step sequence[17] with introduction of the first ring followed by an intramolecular metathesis cyclization or a tandem ring opening−ring closing sequence[18] at slightly elevated temperature and in higher concentration conditions.

In our efforts toward the synthesis of natural and non-natural *Annonaceous* acetogenins[19] and polyether antibiotics,[20] we have developed an efficient application of catalytic intramolecular olefin metathesis of acyclic tetraenes which allows the generation of a variety of polyunsaturated oxygen heterocycles. These polycyclic ethers, and especially tetrahydrofuran units which are directly linked, constitute the core motif of acetogenins whose pharmacological activities have attracted serious attention from chemists[21] and biologists.[22]

We report herein our preliminary results using ruthenium alkylidene **A** as the catalyst in a double ring closing metathesis reaction of acyclic tetraenes. In this process, two rings and two carbon−carbon double bonds are formed in a single step to yield polycyclic unsaturated ethers (Scheme 1). This work completes the initial studies reported by Grubbs[18] for the preparation of bicyclic molecules.

Results and Discussion

The acyclic tetraenes were synthesized starting from commercially available dienes (**1a**, **1b**) as illustrated in Scheme 2. Conversion to epoxides (**2a**, **2b**) using 3-chloroperoxybenzoic acid followed by treatment with an excess of dimethylsulfonium methylide[23] afforded the corresponding one-carbon homologated allyl alcohols (**3a**, **3b**) which were further transformed to allyl ethers (**4a**, **4b**). Alternatively, epoxides (**2a**, **2c**[24]) were treated with vinylmagnesium bromide under copper iodide catalysis to provide alcohols (**5a**, **3c**). Subsequent treatment with allylbromide gave substrates (**6a**, **7a**, **4c**). Isomerization of **4c** using Wilkinson's catalyst yielded to product **5c**. Compound **8a** was prepared by refluxing **7a** in ethyl vinyl ether in the presence of mercury(II) acetate. Treatment of epoxides (**2b**, **2c**) with allylmagnesium bromide furnished alcohols (**5b**, **3d**) which were converted to allyl ethers (**6b**, **4d**).

All the substrates were submitted to the typical metathesis reaction: the starting olefin was solubilized in dry benzene and a catalytic amount of ruthenium catalyst (0.05−0.1 equivalent) was added. The mixture was stirred at room temperature for 30−60 min and subjected to workup and purification. The results are summarized in Table 1. Bis dihydrofuran rings linked by one carbon (entries 1 and 2), two carbons (entry 3), or directly linked (entry 8) were isolated in good yields (70−90%). The reaction also allowed access to seven-membered cyclic ethers (entries 5 and 9, 50−60% yield) and bis dihydropyran rings linked by either two (entry 4, 94% yield) or zero carbons (entry 7, 70% yield). Interestingly, an asymmetric substrate allowed the incorporation of both dihydrofuran and dihydropyran rings linked by two carbons as illustrated in entry 6 (81% yield).

Mechanistically two products were conceivable from the cyclization of substrates **4a**, **4a′**, **4b,** and **4c** resulting from competition between a single RCM reaction leading to cycloalkenes **9b**, **9b′**,[25] **10b**, and **12b** (C-membered ring cyclization) or two RCM reactions (O-membered ring cyclization) yielding **9a**, **9a′**,[25] **10a**, and **12a**. Our results demonstrated that after consumption of the starting substrate (30−60 min), bicyclic compounds were isolated as major products (entry 1, **9a** 76%; entry 2, **9a′** 75%; entry 3, **10a** 72%; entry 7, **12a** 45%), while cyclic alkenes were obtained as minor products (entry 1, **9b** 0%; entry 2, **9b′**[25] <9%; entry 3, **10b** 0%; entry 7, **12b** 19%). The structure of **9b** was unambiguously confirmed by comparison of its analytical data which were identical to those found for an authentic substrate obtained from *cis*-4-cyclopentene-1,3-diol.[26,27] The metathesis reaction of substrates **4a** and **4a′** was completed after 3 h at room temperature with 10 mol % of catalyst to afford only the bicyclic compounds in good yields (entries 1 and 2, **9a**,

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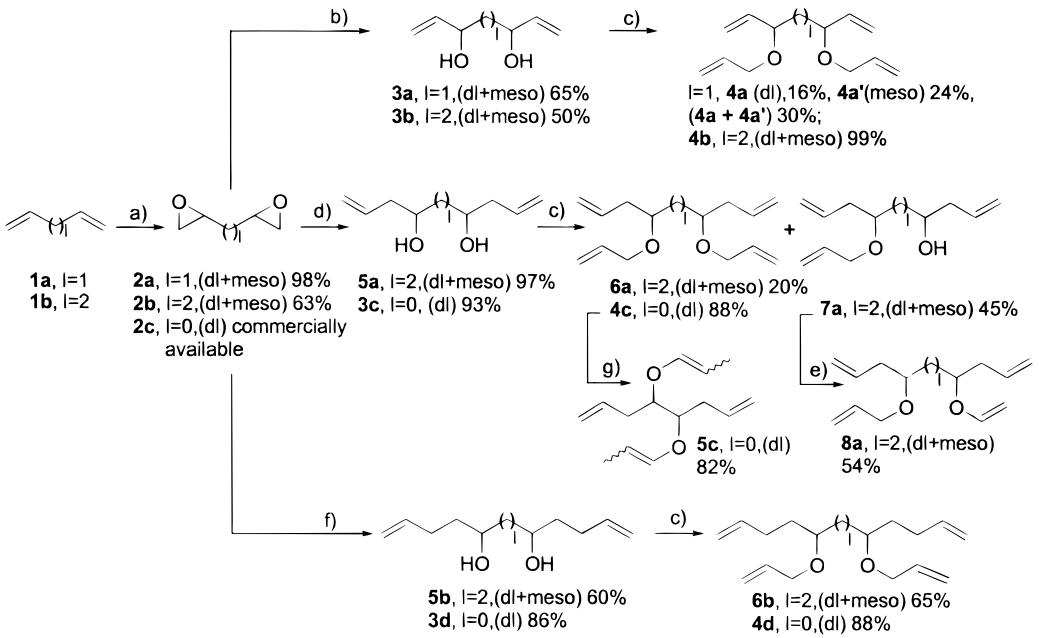
(24) (±)-1,3-Butadiene diepoxide **2c** was purchased from commercial sources.

(25) The analytical data for compounds **9a′** and **9b′** were previously reported by Grubbs.[18] **9b′** was synthesized following the published experimental procedure.[18]

Scheme 2. Synthesis of RCM Substrates[a]



[a] Conditions: (a) *m*-CPBA, CH_2Cl_2, rt, 5−12 h; (b) $(CH_3)_3SI$, *n*-BuLi, THF, −10 °C → rt, 3 h; (c) CH_2=CH-CH_2Br, NaH, DMF/THF, rt, 6 h; (d) CH_2=CHMgBr, CuI, THF, −30 °C, 1−2 h; (e) CH_3CH_2OCH=CH_2, $Hg(OAc)_2$, reflux 48 h; (f) CH_2=CH-CH_2MgBr, CuI, THF, −30 °C, 3 h; (g) $RhCl(PPh_3)_3$, EtOH, reflux 12 h.

9a′: 90%). These results suggested that even if carbocycle products **9b** and **9b′** were formed, they were totally transformed into bicyclic compounds **9a** and **9a′**. Furthermore, when **9b** and **9b′** were submitted to the metathesis reaction for 1 h at room temperature, bicyclic products **9a** and **9a′** were formed respectively resulting from a tandem ring opening−ring closing metathesis similar to that previously observed by Grubbs.[18−28] In contrast to **4a′** (entry 2), **4b** yielded only the bicyclic ether **10a**[29] (entry 3, 72% yield) and the cyclic olefin **10b** was never observed. Nevertheless, for substrate **4c** the product **12b** was obtained in higher yield (entry 7, 19% yield) compared to that of **9b′** (entry 2, <9% yield), but **12b** was totally transformed into the bicyclic compound **12a** after 2 h at 60 °C. These conversions of carbocycle compounds to bicyclic products are driven by the release of highly volatile ethylene and by a gain in entropy. In the other examples (entries 4, 5, 6, 8, and 9) the metathesis products were polycyclic ethers (O-membered ring cyclization) **11a**, **13a**, **14a**, **12a**, **15a**, and **16a** which were isolated as a mixture of diastereoisomers.

Interestingly, the results showed that when both O- and C-membered ring cyclizations were possible by RCM of the starting diene, the formation of a bis O-heterocycle was preferred over C-ring giving an unsaturated biscyclic ether as the major product.

These RCM results obtained under ruthenium carbene **A** catalyst can be explained by two classical reaction mechanisms resulting from the addition of the ruthenium catalyst[30] either to the less hindered double bond (mechanism 1, Scheme 3) or to the more hindered double bond (mechanism 2, Scheme 4).

Mechanism 1 involves an initial intermolecular acyclic metathesis of **4a** with fixation of the ruthenium catalyst at the terminal olefin of the allyl group to generate intermediate **B**. **B** evolves to metallacyclobutane intermediate **C** which after productive cleavage gives the carbene (LnRu=CH_2) and the first ring of **D**.[31] A second diene RCM following the same sequences yields intermediate **E** which forms the second ring (intermediate **F**) and evolves to the bicycle **9a**. We can note that the formation of cyclic alkene **9b** is not feasible with this mechanism (without any ROM−RCM reaction[18−28]) and that intermediate **B** leads directly to bicyclic ethers. The other internal metathesis reactions starting from **B** which would lead to seven- or nine-membered ring compounds are unfavorable.

In mechanism 2, the initial metathesis occurs at the other available olefin moiety of **4a** to yield intermediate **B′**. **B′** is predicted to be minor compared to **B** (mechanism 1) due to steric hindrance. While two cyclizations paths (**a** and **b)** are possible from **B′**, path **a** yielding intermediate **C′** was believed to be the major pathway because products **D**[31] and **4a** were isolated when the reaction was stopped before completion. Path **b** leading to the C-cyclization intermediate **G** was believed to be a minor pathway because the resulting cyclic olefin **9b** was obtained in only low yields (Table 1, entry 2, **9b′** yield <9%), and carbocycle **l0b** (Table 1, entry 3) was never isolated. Furthermore, **9b** was converted to the bicyclic ether **9a**.[28]

Path **a** affords intermediate **C′** and then compound **D** which is similar to mechanism 1. A second diene RCM

(26) **9b** was synthesized by monoalkylation of commercially available *cis*-4-cyclopentene-1,3-diol to give compound **17**. Treatment of **17** under Mitsunobu conditions[27] yielded ester **18** having complete inversion of configuration. Hydrolysis of **18** followed by alkylation of alcohol **19** afforded **9b.** For experimental details and analytical data, see the Experimental Section.

(27) Mitsunobu, O. *Synthesis* **1981**, 1.

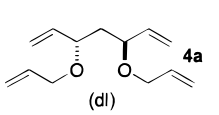
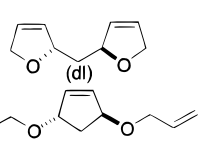
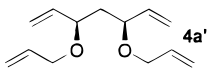
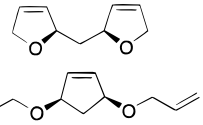
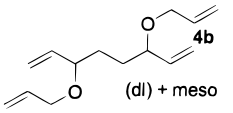
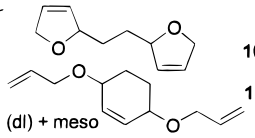
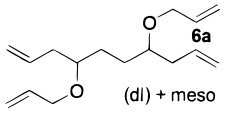
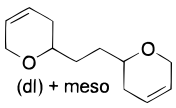
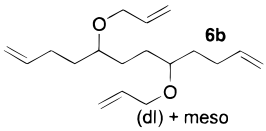
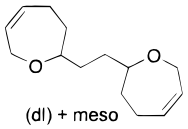
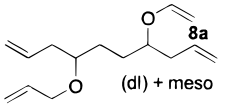
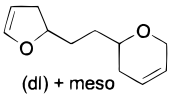
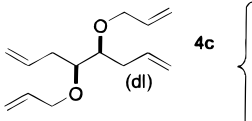
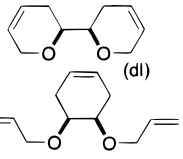
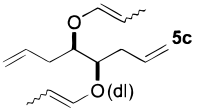
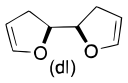
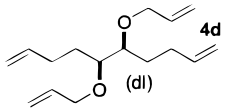
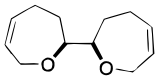
(28) Complete conversion of **9b** to **9a** was observed after 45 min at 25 °C. The metathesis reaction for **9b′** was slower, and after 3 h at 25 °C product **9a′** was isolated in 80% yield in addition to recovered **9b′**. Both products **9a** and **9a′** are the result of a tandem ring opening−ring closing metathesis (ROM−RCM reaction).[18]

(29) **10a** was isolated as a mixture of diastereoisomers.

(30) The reviewers had very helpful comments concerning the reaction mechanism and the involved intermediates.

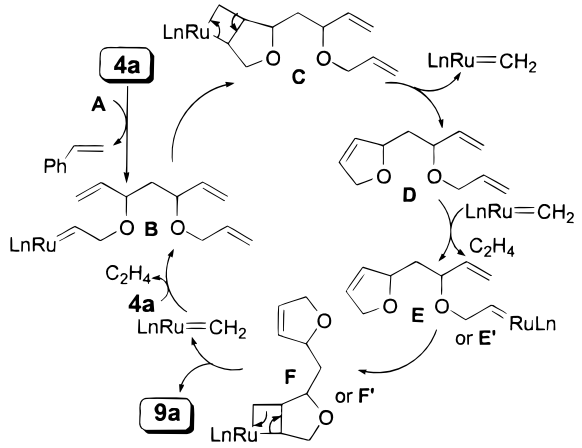
(31) **D** was isolated and identified when the RCM reaction was stopped before complete consumption of the starting material. Analytical data are reported in the Experimental Section.

Table 1. Results of the RCM of Tetraenes

Entry	Substrate	Product	Yield*
1			**9a** 76%[a] 90%[b] **9b** 0%[a] 0%[b]
2			**9a'** 75%[a] 90%[b] **9b'** <9%[a] 0%[b]
3			**10a** 72%[a] **10b** 0%[a]
4			**11a** 94%[a]
5			**13a** 60%[a]
6			**14a** 81%[a]
7			**12a** 45%[a] 70%[c] **12b** 19%[a] 0%[c]
8			**15a** 70%[d]
9			**16a** 50%[a]

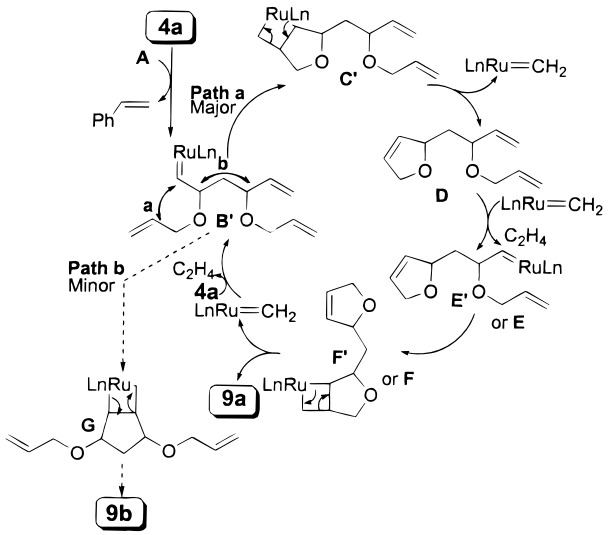
* isolated yield; a) 5-10mol% **A**, dry C_6H_6, 1 hour, rt ; b) 10mol% **A**, dry C_6H_6, 3 hours, rt; c) 2 hours at 60°C in dry C_6H_6; d) 6 hours at 60°C in dry C_6H_6.

Scheme 3. Mechanism 1



following the same sequence yields intermediate **E**′ which generates the second ring (intermediate **F**′) to afford the bicycle **9a**. In both mechanisms (mechanism 1, Scheme 3; mechanism 2, Scheme 4) the generation of compound **9a** from product **D** can be rationalized by two routes, through intermediate **E** or intermediate **E**′.

Scheme 4. Mechanism 2



Noting that the bicyclic ethers were isolated as major products (entries 1−9) and the addition of the ruthenium catalyst on the olefin should be governed by steric effects, mechanism 1 is expected to predominate over mechanism 2. In entries 1−6 the ruthenium catalyst added to the less hindered olefin of the allyl group, following mechanism 1. In entries 7−9 the differentiation of the terminal olefins is more difficult and can explain the C-cylization product (**12b**, 19% yield). This suggests that the intermediate **B**′ in mechanism 2 is not excluded and should evolve following path **b**. In the case of product **5c** (entry 8), which is bearing substituted olefins, the Ru catalyst adds on the unsubstituted olefins to give **15a** as single product, and as reported previously,[6,7] any olefin substitution appears to slow the RCM (**15a**: 70% yield after 6 h at 60 °C). In entries 4−6, mechanism 2 following path **b** would have generated eight- or ten-membered rings which are not entropically favored.

Presumably, we can deduce that the RCM reaction of acyclic tetraenes using **A** as the catalyst is occurring via O-membered cyclization to yield bis polycyclic ethers as major products following mechanism 1. When C-cyclization products were formed (path **b**, mechanism 2, Scheme 4) they were totally transformed to bicyclic compounds owing to the release of highly volatile ethylene.

Conclusion

In summary, we have presented herein metathesis-based methodology for the construction of bis polycyclic ethers or enol ethers linked by none, one, or two carbons through a double metathesis reaction. We have shown that RCM reactions of tetraenes bearing unsaturated ether functions produce polycyclic ethers as major products. The application of this bis ring closing metathesis reaction for the preparation of acetogenins and for the synthesis of other substituted cyclic ethers is being investigated.

Experimental Section

General Methods. All reagents were commercial grade and were used as received without further purification. Bis(tricyclohexylphosphine)benzylidine ruthenium(IV) dichloride was pur-

chased from Strem Chemical INC. All reactions were performed under an inert atmosphere, and anhydrous solvents were dried and distilled before use. Thin layer chromatograms (TLC) and flash chromatography separations were respectively performed on precoated silica gel 60 F254 plates (Merck, 0.25 mm) and on Merck silica gel 60 (230−400 mesh). ^{1}H NMR spectra were recorded at 300 MHz in $CDCl_3$; shifts are relative to internal TMS. ^{13}C NMR spectra were obtained at 75 MHz with $CDCl_3$ as internal reference. Mass spectra were recorded at 70 eV using chemical ionization mode (CI-NH_3). High-resolution mass spectra HRMS:LSIMS$^+$ were recorded on a Zabspec TOF Micromass (matrix: 3-nitrobenzyl alcohol). IR spectra were recorded as casts on an FT instrument.

General Procedure for Metathesis Reaction: Preparation of 9a, 9a′, 10a, 11a, 12a, 13a, 14a, and 16a. To a stirred solution of tetraene (90 mg, 0.43 mmol) in 3 mL of dry benzene at room temperature was added a solution of bis(tricyclohexylphosphine)benzylidine ruthenium(IV) dichloride (18 mg, 0.022 mmol) in 2 mL of dry benzene. The reaction mixture was stirred for 1 h at room temperature and was concentrated under vacuum. The crude product was purified by column chromatography on silica gel with pentane/ether to yield the bicyclic compound.

1,4-Pentadiene Diepoxide (2a). To a stirred solution of 1,4-pentadiene (7 mL, 67.6 mmol) in dry CH_2Cl_2 (150 mL) at 0 °C was added *m*-chloroperoxybenzoic acid (48.6 g, 169 mmol, 57−60% by wt.) in five portions. The reaction mixture was stirred overnight at room temperature and was quenched with saturated aqueous $NaHCO_3$ solution (100 mL). The organic layer was separated, washed with 1 M KOH (7 × 50 mL), dried ($MgSO_4$), and concentrated to give the diepoxide **2a** (7.5 g, 98% yield) which was used directly in the next step: ^{1}H NMR ($CDCl_3$) δ 3.09−2.99 (m, 2H), 2.80−2.75 (m, 2H), 2.56 (dd, J = 2.8, 4.9 Hz, 1H), 2.50 (dd, J = 2.8, 5.0 Hz, 1H), 1.77−1.70 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 49.1, 48.6, 46.6, 46.0, 35.6, 34.6; IR (neat, cm^{-1}) 2997, 1218, 845; MS (DCI/NH_3) *m*/*z* (MNH_4^+) = 118.

1,6-Heptadiene-3,5-diol (3a). To a stirred solution of trimethylsulfonium iodide (47 g, 230.7 mmol) in dry THF (400 mL) at −10 °C was added dropwise butyllithium (140 mL, 1.6 M in hexane). The reaction mixture was stirred at −10 °C for 1 h, and a solution of diepoxide **2a** (3.85 g, 38.45 mmol) in dry THF (20 mL) was added. The reaction mixture was allowed to warm to room temperature, and the white suspension was stirred overnight. The mixture was treated with a saturated aqueous NH_4Cl solution (100 mL), extracted with CH_2Cl_2 (4 × 75 mL), dried over $MgSO_4$, and concentrated. The crude product was purified on silica gel (pentane/ether 50/50) to yield the compound **3a** (3.1 g, 65% yield):^{1}H NMR ($CDCl_3$) δ 5.90−5.79 (m, 2H), 5.25 (dd, J = 3.2, 14.3 Hz, 2H), 5.11 (dd, J = 2.9, 8.0 Hz, 2H), 4.40−4.33 (m, 2H), 3.55 (br s, 1H), 3.20 (br s, 1H), 1.75−1.60 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 140.6, 114.7, 114.6, 73.1, 70.3, 43.0, 42.1; IR (neat, cm^{-1}) 3357; 1425, 992, 925; MS (DCI/NH_3) *m*/*z* (MH)$^+$ = 129, (MNH_4^+) = 146.

***dl*-3,5-Bis-allyloxy-hepta-1,6-diene (4a), *meso*-3,5-Bis-allyloxy-hepta-1,6-diene (4a′).** To a stirred solution of diol **3a** (3.1 g, 24.19 mmol) in dry THF (150 mL) at 0 °C was added sodium hydride (3.9 g, 96.75 mmol, 60% dispersion in mineral oil). The reaction mixture was stirred at room temperature for 15 min and was cooled to 0 °C, and allyl bromide (8.4 mL, 96.75 mmol) in dry DMF (50 mL) was added. The reaction mixture was stirred for 12 h at room temperature, hydrolyzed with saturated NH_4Cl (75 mL), extracted with Et_2O, washed with saturated NaCl (3 × 50 mL), and dried ($MgSO_4$). After concentration, the crude product was purified by column chromatography (pentane/ether 97/3) to give **4a′** (1.20 g, 24% yield), **4a** + **4a′** (1.45 g, 30% yield), and **4a** (0.81 g, 16% yield). **4a**: ^{1}H NMR ($CDCl_3$) δ 5.96−5.84 (m, 2H), 5.74−5.62 (m, 2H), 5.28−5.12 (m, 8H), 4.08−3.93 (m, 4H), 3.80 (dd, J = 5.6, 11.8 Hz, 2H), 1.68 (dd, J = 6.2, 7. 2 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 139.0, 135.3, 116.7, 116.6, 76.7, 69.6, 42.1; IR (neat, cm^{-1}) 3080, 2860, 1083, 993, 924; MS (DCI/NH_3) *m*/*z* (MH)$^+$ = 209, (MNH_4^+) = 226. **4a′**: ^{1}H NMR ($CDCl_3$) δ 5.94−5.80 (m, 2H), 5.73−5.61 (m, 2H), 5.27−5.10 (m, 8H), 4.01 (dd, J = 1.5, 5.3 Hz, 2H), 3.86−3.73 (m, 4H), 2.06−1.96 (m, 1H), 1.60−1.51 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 138.7, 135.2, 117.4, 116.6, 77.7, 69.3, 41.3; IR (neat, cm^{-1}) 3080, 2861, 1081, 994, 924; MS (DCI/NH_3) *m*/*z* (MH)$^+$ =209, (MNH_4^+) = 226.

***dl*-Bis-(5-oxa-2cyclopentenyl) mmethane (9a).** From **4a** (100 mg, 0.49 mmol), **9a** was obtained (55 mg, 76% yield) following the general procedure, or **9a** (65 mg, 90% yield) when the reaction mixture was stirred for 3 h at room temperature: ^{1}H NMR ($CDCl_3$) δ 5.86−5.79 (m, 4H), 4.97−4.91 (m, 2H), 4.65−4.52 (m, 4H), 1.72 (dd, J = 6.2, 6.3 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 130.4, 126.2, 83.6, 74.8, 42.6; IR (neat, cm^{-1}) 2850, 1755, 1353, 1074; MS (DCI/NH_3) *m*/*z* (MH)$^+$ = 153, (MNH_4^+) = 170.

***meso*-Bis-(5-oxa-2cyclopentenyl)methane (9a′).** From **4a′** (100 mg, 0.49 mmol), **9a′** was obtained (55 mg, 75% yield) following the general procedure, or **9a′** (66 mg, 90% yield) when the reaction mixture was stirred for 3 h at room temperature: ^{1}H NMR ($CDCl_3$) δ 5.86−5.80 (m, 4H), 4.92−4.90 (m, 2H), 4.66−4.52 (m, 4H), 1.88−1.72 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 130.0, 126.4, 83.3, 75.0, 41.8; IR (neat, cm^{-1}) 2851, 1755, 1352, 1073. MS (DCI/NH_3) *m*/*z* (MH)$^+$ = 153, (MNH_4^+) = 170; HRMS cald for $C_{19}H_{12}O_2$ =152,0837, found 152,0827.

***dl*-2-(2-Allyloxy-but-3-enyl)-2,5-dihydrofuran (D).** The ether **D** was prepared in a manner similar to that of **9a′** when the reaction was stopped after 15 min. Purification of the crude material gave **9a** (45 mg, 60% yield) and **D** (8 mg, 10% yield). **D**: ^{1}H NMR ($CDCl_3$) δ 5.98−5.64 (m, 4H), 5.28−5.17 (m, 4H), 5.16−5.12 (m, 1H), 4.64−4.59 (m, 2H), 4.07−3.82 (m, 3H), 1.82−1.71 (m, 1H), 1.64−1.57 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 139.1, 135.2, 130.5, 126.2, 116.8, 116.6, 83.7, 83.0, 74.8, 69.6, 42.6; IR (neat, cm^{-1}) 2926, 2855, 1741, 1075; MS (DCI/NH_3) *m*/*z* (MH)$^+$ = 181, (MNH_4^+) = 198.

1,5-Hexadiene Diepoxide (2b). To a stirred solution of 1,5-hexadiene (3.6 mL, 30 mmol) in dry CH_2Cl_2 (60 mL) was added at 0 °C *m*-chloroperbenzoic acid (12.95 g, 75 mmol, 57−86% by wt) in four portions. After 24 h at room temperature, 15 mL of water was added and the solution was extracted with CH_2Cl_2 (3 × 10 mL). The organic layer was washed with 1 N KOH (6 × 25 mL), dried over $MgSO_4$, and concentrated. Flash chromatography (hexane/ether 70/30) gave the diepoxide **2b** (2.16 g, 63% yield): ^{1}H NMR ($CDCl_3$) δ 2.89−2.87 (m, 2H), 2.69 (dd, J = 4.7, 4.7 Hz, 2H), 2.42 (dd, J = 2.5, 4.9 Hz, 2H), 1.73−1.53 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 51.8, 51.5, 46.9, 29.2, 28.7; IR (neat, cm^{-1}) 2991, 1262, 926, 837; MS (DCI/NH_3) *m*/*z* (MH)$^+$ = 115, (MNH_4^+) = 132.

Octa-1,7-diene-3,6-diol (3b). To a stirred mixture of trimethylsulfonium iodide (6.12 g, 30 mmol) in 50 mL of dry THF was added at −10 °C butyllithium (18 mL, 1.6 M in hexane). The resulting mixture was stirred at −10 °C for 30 min, and a solution of diepoxide **2b** (570 mg, 5 mmol) in dry THF (5 mL) was added. The reaction mixture was stirred at room temperature for 3 h, hydrolyzed with saturated NH_4Cl (15 mL), extracted with CH_2Cl_2 (3 × 10 mL), dried over $MgSO_4$, and concentrated. The crude product was purified by column chromatography (hexane/ether 50/50) to yield compound **3b** (360 mg, 50% yield): ^{1}H NMR ($CDCl_3$) δ 5.86−5.74 (m, 2H), 5.17 (dd, J = 2.3, 16.1 Hz, 2H), 5.03 (dd, J = 2.2, 2.9 Hz, 2H), 4.07−4.04 (m, 2H), 3.57 (br s, 1H), 3.44 (br s, 1H), 1.62−1.56 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 141.0, 114.6, 114.5, 72.9, 72.6, 33.2, 32.6; IR (neat, cm^{-1}) 3345, 1426, 990, 921; MS (DCI/NH_3) *m*/*z* (MH)$^+$ =143, (MNH_4^+) = 160.

3,6-Bis-allyloxy-octa-1,7-diene (4b). To a stirred solution of diol **3b** (250 mg, 1.76 mmol) in dry THF (10 mL) was added at 0 °C sodium hydride (285 mg, 7.03 mmol, 60% dispersion in mineral oil). The reaction mixture was stirred at room temperature for 15 min and cooled to 0 °C. Allyl bromide (0.61 mL, 7.03 mmol) in dry DMF (10 mL) was added, and the mixture was stirred at room temperature for 4 h. The reaction was quenched with saturated NH_4Cl (10 mL) and extracted with CH_2Cl_2 (4 × 10 mL). The organic layer was dried over $MgSO_4$ and concentrated. The crude product was purified by column chromatography (hexane/ether 90/10) to yield **4b** (390 mg, 99% yield): ^{1}H NMR ($CDCl_3$) δ 5.94−5.81 (m, 2H), 5.68−5.58 (m, 2H), 5.26−5.10 (m, 8H), 4.01 (dd, J = 5.2, 12.8 Hz, 2H), 3.79 (dd, J = 6.6, 12.7 Hz, 2H), 3.70−3.65 (m, 2H), 1.72−1.48 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 139.0, 135.3, 117.0, 116.6, 80.7, 80.5, 69.2, 31.4, 31.2; IR (neat, cm^{-1}) 2846, 1075; MS (DCI/NH_3) *m*/*z* (MH)$^+$ = 223, (MNH_4^+) = 240.

1,2-Bis-(5-oxa-2-cyclopentenyl) ethane (10a). From **4b** (100 mg, 0.45 mmol) the bicycle **10a** was obtained (51 mg, 72% yield) following the general procedure: ^{1}H NMR ($CDCl_3$) δ 5.85−5.82 (m, 2H), 5.74−5.72 (m, 2H), 4.84−4.80 (m, 2H), 4.65−4.52 (m, 4H), 1.68−1.50 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 129.7, 126.6,

86.0, 85.8, 75.1, 31.4, 31.3; IR (neat, cm^{-1}) 3079, 2925, 1079; MS (DCI/NH_3) m/z $(MH)^+ = 167$, $(MNH_4^+) = 184$.

Octa-1,7-diene-4,5-diol (3c). To cooled (−30 °C) copper(I) iodide (4 g, 20 mmol) were added dropwise a solution of vinylmagnesium bromide (200 mL, 200 mmol, 1 M in THF) and commercially available (±)-1,3-butadiene diepoxide **2c** (5.2 mL, 66.7 mmol). The reaction mixture was stirred at −30 °C for 1 h, hydrolyzed with saturated NH_4Cl (50 mL), and extracted with Et_2O (3 × 40 mL). The organic layer was separated, dried over $MgSO_4$, and concentrated. The crude product was purified by column chromatography (pentane/ether 50/50) to yield the diol **3c** (9.3 g, 93% yield): ^1H NMR ($CDCl_3$) δ 5.90−5.76 (m, 2H), 5.16−5.08 (m, 4H), 3.55−3.44 (m, 2H), 2.51 (br s, 2H), 2.36−2.20 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 134.6, 118.1, 72.8, 38.3; IR (neat, cm^{-1}) 3397, 1642, 996, 916; MS (DCI/NH_3) m/z $(MNH_4^+) = 160$.

4,5-Bis-allyloxy-octa-1,7-diene (4c). To a solution of diol **3c** (500 mg, 3.52 mmol) in dry THF (30 mL) at 0 °C was added NaH (425 mg, 10.55 mmol, 60% dispersion in mineral oil). The resulting mixture was stirred at room temperature for 15 min and cooled to 0 °C. A solution of allyl bromide (0.92 mL, 10.55 mmol) in dry DMF (10 mL) was added, and the mixture was stirred at room temperature for 45 min. NaH (140 mg, 3.51 mmol) and allyl bromide (0.3 mL, 3.51 mmol) were added, and the reaction mixture was stirred at room temperature for 4 h. The mixture was hydrolyzed with saturated NH_4Cl (25 mL) and extracted with Et_2O (3 × 25 mL). The organic layer was separated and dried ($MgSO_4$). The crude product was purified by column chromatography (pentane/ether 95/5) to give **4c** (650 mg, 88% yield): ^1H NMR ($CDCl_3$) δ 5.94−5.77 (m, 4H), 5.27−5.01 (m, 8H), 4.09−3.99 (m, 4H), 3.42−3.36 (m, 2H), 2.42−2.33 (m, 2H), 2.28−2.19 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 135.5, 116.8, 116.7, 79.8, 71.8, 34.8; IR (neat, cm^{-1}) 3079, 2925, 1085, 996, 915; MS (DCI/NH_3) m/z $(MH)^+ = 223$, $(MNH_4^+) = 240$.

***dl*-5,5-Bis(6-oxa-2-cyclohexene) (12a).** From **4c** (100 mg, 0.45 mmol) **12a** (53 mg, 70% yield) was prepared following the general procedure except that the mixture was heated to 60 °C for 2 h: ^1H NMR ($CDCl_3$) δ 5.82−5.67 (m, 4H), 4.30−4.15 (m, 4H), 3.55−3.47 (m, 2H), 2.14−2.07 (m, 2H), 1.93−1.84 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 126.6, 123.6, 75.8, 66.2, 26.5; IR (neat, cm^{-1}) 3034, 2927, 1183, 1098; MS (DCI/NH_3) m/z $(MH)^+ = 167$, $(MNH_4^+) = 184$; HRMS cald for $C_{10}H_{14}O_2 = 166{,}0994$, found 166,0995.

***trans*-4,5-Bis-allyloxy-cyclohexene (12b).** From **4c** (100 mg, 0.45 mmol) **12a** (34 mg, 45% yield) and **12b** (16 mg, 19%) were prepared following the general procedure. **12b**: ^1H NMR ($CDCl_3$) δ 5.99−5.86 (m, 2H), 5.53−5.52 (m, 2H), 5.27 (dd, J = 3.5, 18.9 Hz, 2H), 5.13 (dd, J = 3.6, 10.3 Hz, 2H), 4.21−4.09 (m, 4H), 3.59−3.53 (m, 2H), 2.48−2.40 (m, 2H), 2.11−2.03 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 135.5, 124.2, 116.3, 77.4, 71.1, 30.7; IR (neat, cm^{-1}) 3080, 2923, 1139, 1091, 994, 921; MS (DCI/NH_3) m/z $(MH)^+ = 195$, $(MNH_4^+) = 212$.

4,5-Bis-propenyloxy-octa-1,7-diene (5c). To a solution of **4c** (3.25 g, 14.6 mmol) in MeOH (100 mL) was added Wilkinson's catalyst (chlorotris(triphenylphosphine)rhodium(I), 950 mg, 1.02 mmol), and the resulting mixture was heated at 60 °C for 12 h. The solution was concentrated under vacuum, and the crude product was purified on silica gel (pentane/ether 97/3) to give **5c** (2.65 g, 82% yield): ^1H NMR ($CDCl_3$) δ 6.10−5.94 (m, 2H), 5.86−5.74 (m, 2H), 5.13−5.04 (m, 4H), 4.94−4.86 (m, 2H), 3.71−3.63 (m, 2H), 2.42−2.29 (m, 4H), 1.59−1.50 (m, 6H); ^{13}C NMR ($CDCl_3$) δ 146.4, 145.5, 134.4, 134.3, 117.6, 117.5, 101.4, 101.1, 80.6, 80.0, 34.9, 34.4, 12.4; IR (neat, cm^{-1}) 3080, 2923, 1674, 995, 918; MS (DCI/NH_3) m/z $(MH)^+ = 223$, $(MNH_4^+) = 240$.

***dl*-4,4′-Bis(5-oxa-1-cyclopentene) (15a).** From **5c** (150 mg, 0.67 mmol) the bicycle **15a** was obtained (65 mg, 70% yield) following the general procedure except that the reaction mixturewas heated to 60 °C for 6 h: ^1H NMR ($CDCl_3$) δ 6.32−6.29 (m, 2H), 4.89−4.86 (m, 2H), 4.65−4.59 (m, 2H), 2.73−2.64 (m, 2H), 2.43−2.34 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 145.5, 99.0, 82.2, 31.0; IR (neat, cm^{-1}) 2931, 1622; MS (DCI/NH_3) m/z $(MH)^+ = 139$, $(MNH_4^+) = 173$; HRMS cald for $C_8H_{10}O_2 = 138{,}0681$, found 138,0685.

Deca-1,9-diene-4,7-diol (5a). To cooled (−30 °C) copper(I) iodide (315 mg, 1.58 mmol) was added dropwise vinylmagnesium bromide (15.8 mL, 15.8 mol, 1 M in THF), and the reaction mixture was stirred at −30 °C for 5 min. A solution of diepoxide **2b** (600 mg, 5.26 mmol) in dry THF (6 mL) was added, and the mixture was stirred at −30 °C for 30 min. The reaction mixture was hydrolyzed with saturated NH_4Cl (10 mL) and extracted with Et_2O (3 × 10 mL), and the organic layer was separated, dried over $MgSO_4$, and concentrated. The crude product was purified by column chromatography (hexane/ether 50/50) to yield the diol **5a** (860 mg, 97% yield): ^1H NMR ($CDCl_3$) δ 5.83−5.72 (m, 2H), 5.11−5.06 (m, 4H), 3.65−3.61 (m, 2H), 2.90 (br s, 1H), 2.50 (br s, 1H), 2.27−2.14 (m, 4H), 1.68−1.46 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 134.9, 134.7, 118.2, 117.9, 71.2, 70.5, 42.2, 41.9, 33.5, 32.6; IR (neat, cm^{-1}) 3352, 2928, 1434, 995, 914; MS (DCI/NH_3) m/z $(MH)^+ = 171$, $(MNH_4^+) = 188$.

4,7-Bis-allyloxy-deca-1,9-diene (6a), 7-Allyloxy-4-deca-1,9-dien-4-ol (7a). To a stirred solution of diol **5a** (380 mg, 2.23 mmol) in dry THF (10 mL) at 0 °C was added NaH (180 mg, 4.46 mmol, 60% dispersion in mineral oil). The reaction mixture was stirred at room temperature for 15 min, cooled to 0 °C, and added to a solution of allyl bromide (0.4 mL, 4.46 mmol) in 10 mL of dry DMF. The reaction mixture was stirred at room temperature for 2 h , quenched with saturated NH_4Cl (10 mL), and extracted with Et_2O (3 × 5 mL). The organic layer was dried over $MgSO_4$ and concentrated. The crude product was purified on silica gel (hexane/ether 90/10) to yield **7a** (210 mg, 45% yield) and **6a** (110 mg, 20% yield). **6a**: ^1H NMR ($CDCl_3$) δ 5.94−5.76 (m, 4H), 5.28−5.01 (m, 8H), 4.05−3.91 (m, 4H), 3.37−3.34 (m, 2H), 2.31−2.20 (m, 4H), 1.63−1.45 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 135.5, 135.0, 117.0, 116.6, 78.7, 78.4, 70.1,, 38.5, 38.4, 29.6, 29.1; IR (neat, cm^{-1}) 3080, 2927, 1079, 995, 914; MS (DCI/NH_3) m/z $(MH)^+ = 251$, $(MNH_4^+) = 268$. **7a**: ^1H NMR ($CDCl_3$) δ 5.93−5.79 (m, 3H), 5.28−5.02 (m, 6H), 4.04−3.95 (m, 3H), 3.65 (br s, 1H), 3.39−3.37 (m, 1H), 2.34−2.15 (m, 4H), 1.65−1.52 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 135.1, 134.7, 117.7, 117.1, 116.8, 78.7, 78.5, 70.8, 70.1, 70.0, 42.0, 38.2, 32.6, 29.9; IR (neat, cm^{-1}) 3404, 2927, 1070, 996, 914; MS (DCI/NH_3) m/z $(MH)^+ = 211$, $(MNH_4^+) = 228$.

***dl*-1,2-Bis(6-oxa-3 cyclohexenyl)ethane (11a).** From **6a** (60 mg, 0.24 mmol) the bicycle **11a** was obtained (47 mg, 94% yield) following the general procedure: ^1H NMR ($CDCl_3$) δ 5.80−5.66 (m, 4H), 4.15 (br s, 4H), 3.52−3.43 (m, 2H), 2.00−1.97 (m, 4H), 1.70−1.51 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 126.4, 124.4, 73.9, 73.4, 66.0, 32.3, 31.5, 31.3, 31.0; IR (neat, cm^{-1}) 2912, 1181, 1091; MS (DCI/NH_3) m/z $(MH)^+ = 195$, $(MNH_4^+) = 212$; HRMS cald for $C_{12}H_{18}O_2 = 194{,}1307$, found 194,1310.

4-Allyloxy-7-vinyloxy-deca-1,9-diene (8a). To a solution of **7a** (192 mg, 0.87 mmol) in ethyl vinyl ether (5 mL) was added mercury(II) acetate (140 mg, 0.44 mmol), and the mixture was heated to reflux for 48 h. The solvent was removed under vacuum, and the crude product was purified on silica gel (hexane/ether 90/10) to give **8a** (110 mg, 54% yield) and recovered **7a** (75 mg, 40% yield). **8a**: ^1H NMR ($CDCl_3$) δ 6.30 (dd, J = 6.6, 14.1 Hz, 1H), 5.89−5.74 (m, 3H), 5.29−5.02 (m, 6H), 4.26 (dd, J = 1.6, 14.1 Hz, 1H), 4.01−3.95 (m, 3H), 3.78−3.74 (m, 1H), 3.38−3.32 (m, 1H), 2.35−2.22 (m, 4H), 1.71−1.49 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 151.3, 135.4, 134.6, 134.1, 117.5, 117.0, 116.5, 88.2, 79.6, 79.1, 78.5, 78.1, 70.0, 69.9, 38.6, 38.4, 38.3, 29.6, 29.5, 29.2, 29.0; IR (neat, cm^{-1}) 3079, 2926, 1634, 1195, 996, 916; MS (DCI/NH_3) m/z $(MH)^+ = 237$, $(MNH_4^+) = 254$.

1,2-[5-Oxa-1 cyclopentenyl][6-oxa-2 cyclohexenyl]ethane (14a). From **8a** (80 mg, 0.34 mmol) the bicycle **14a** was obtained (49 mg, 81% yield) following the general procedure: ^1H NMR ($CDCl_3$) δ 6.25−6.22 (m, 1H), 5.80−5.66 (m, 2H), 4.84−4.80 (m, 1H), 4.56−4.48 (m, 1H), 4.17−4.13 (m, 2H), 3.51−3.47 (m, 1H), 2.72−2.63 (m, 1H), 2.28−2.19 (m, 1H), 2.02−1.96 (m, 2H), 1.73−1.52 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 145.0, 126.4, 124.3, 99.0, 81.7, 81.2, 73.7, 73.3, 66.0, 34.9, 34.7, 32.4, 32.1, 31.9, 31.5, 31.3, 31.2; IR (neat, cm^{-1}) 2926, 1619, 1091; MS (DCI/NH_3) m/z $(MH)^+ = 181$, $(MNH_4^+) = 198$.

Dodeca-1,11-diene-5,8-diol (5b). To a cooled solution (−30 °C) of copper(I) iodide (525 mg, 2.6 mmol) in dry Et_2O (5 mL) was added dropwise of allylmagnesium bromide (26.3 mL, 26.3 mmol, 1 M in THF), and the solution was stirred at −30 °C for 5 min. A solution of **2b** (1 g, 8.76 mmol) in dry Et_2O (5 mL) was added, and the mixture was stirred at −30 °C for 2 h, hydrolyzed with saturated NH_4Cl (15 mL), and extracted with Et_2O (3 × 10 mL). The organic layer was separated, dried over $MgSO_4$, and concentrated. The crude product was purified by column

chromatography (hexane/ether 50/50) to yield the diol **5b** (1.03 g, 60% yield): ^{1}H NMR ($CDCl_3$) δ 5.86−5.71 (m, 2H), 5.02−4.68 (m, 4H), 3.63−3.34 (m, 4H), 2.19−2.02 (m, 4H), 1.64−1.38 (m, 8H); ^{13}C NMR ($CDCl_3$) δ 138.6, 138.5, 114.7, 71.7, 71.1, 36.8, 36.3, 34.1, 33.0, 30.1; IR (neat, cm^{-1}) 3354, 2928, 996, 910; MS (DCI/NH_3) *m*/*z* $(MH)^+ = 199$, $(MNH_4^+) = 216$.

5,8-Bis-allyloxy-dodeca-1,11-diene (6b). To a solution of diol **5b** (200 mg, 1.01 mmol) in dry THF (3 mL) at 0 °C was added NaH (80 mg, 2.02 mmol, 60% dispersion in mineral oil), and the reaction mixture was stirred at room temperature for 15 min. The mixture was cooled to 0 °C, and allyl bromide (0.18 mL, 2.02 mmol) was added. After 1 h at room temperature were added NaH (80 mg, 2.02 mmol) and allyl bromide (0.18 mL, 2.02 mmol), and the reaction mixture was stirred at room temperature for 2 h. The mixture was hydrolyzed with saturated NH_4Cl (5 mL) and extracted with Et_2O (3 × 10 mL). The organic layer was separated and dried ($MgSO_4$). The crude product was purified by column chromatography (hexane/ether 90/10) to give **6b** (170 mg, 65% yield): ^{1}H NMR ($CDCl_3$) δ 5.94−5.72 (m, 4H), 5.24 (dd, J = 1.6, 18.8 Hz, 2H), 5.12 (dd, J = 1.3, 10.4 Hz, 2H), 4.99 (dd, J = 1.7, 21.0 Hz, 2H), 4.94 (dd, J = 1.7, 15.8 Hz, 2H), 3.95 (dd, J = 1.0, 5.1 Hz, 4H), 3.33−3.29 (m, 2H), 2.15−2.05 (m, 4H), 1.66−1.45 (m, 8H); ^{13}C NMR ($CDCl_3$) δ 138.7, 135.5, 116.4, 114.5, 78.5, 78.3, 70.0, 69.9, 33.2, 33.1, 29.7, 29.4, 29.0; IR (neat, cm^{-1}) 3078, 2937, 1081, 994, 914; MS (DCI/NH_3) *m*/*z* $(MH)^+ = 279$, $(MNH_4^+) = 296$.

1,2-Bis(7-oxa-2 cycloheptadienyl)ethane (13a). From **6b** (100 mg, 0.36 mmol) the bicycle **13a** was obtained (48 mg, 60% yield) following the general procedure: ^{1}H NMR ($CDCl_3$) δ 5.84−5.76 (m, 2H), 5.66−5.61 (m, 2H), 4.26 (dd, J = 4.6, 16.1 Hz, 2H), 4.00 (dd, J = 4.7, 13.6 Hz, 2H), 3.60−3.52 (m, 2H), 2.38−2.30 (m, 2H), 2.17−2.13 (m, 2H), 1.93−1.63 (m, 2H), 1.71−1.45 (m, 6H); ^{13}C NMR ($CDCl_3$) δ 131.9, 130.2, 81.6, 80.9, 67.0, 66.9, 34.4, 34.3, 33.1, 32.4, 26.1, 26.0; IR (neat, cm^{-1}) 3019, 2927, 1124; MS (DCI/NH_3) *m*/*z* $(MH)^+ = 223$, $(MNH_4^+) = 240$; HRMS calcd for $C_{14}H_{23}O_2$ $(MH^+) = 223{,}1698$, found 223,1698.

Deca-1,9-diene-5,6-diol (3d). To a solution of allylmagnesium bromide (58 mL, 58.14 mmol, 1 M in THF) at −30 °C was added copper iodide, and the resulting mixture was stirred at −30 °C for 5 min. Commercially available (±)-1,3-butadiene diepoxide **2c** (1.5 mL, 19.38 mmol) was added, and the solution was stirred at −30 °C for 1 h. The reaction was quenched with saturated NH_4Cl (25 mL), extracted with Et_2O, and dried ($MgSO_4$). The crude product was purified on silica gel (pentane/ether 50/50) to yield **3d** (2.4 g, 86% yield): ^{1}H NMR ($CDCl_3$) δ 5.87−5.73 (m, 2H), 5.06−4.93 (m, 4H), 3.43−3.38 (m, 2H), 2.84 (d, J = 4.1 Hz, 2H), 2.26−2.07 (m, 4H), 1.62−1.49 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 138.4, 115.1, 74.0, 32.8, 30.0; IR (neat, cm^{-1}) 3377, 2940, 1437, 996, 913; MS (DCI/NH_3) *m*/*z* $(MNH_4^+) = 188$.

5,6-Bis-allyloxy-deca-1,9-diene (4d). To a solution of diol **3d** (500 mg, 2.94 mmol) in dry THF (30 mL) at 0 °C was added NaH (470 mg, 11.76 mmol, 60% dispersion in mineral oil), and the reaction mixture was stirred for 15 min at room temperature. The mixture was cooled to 0 °C, and a solution of allyl bromide (1.02 mL, 11.76 mmol) in dry DMF (10 mL) was added. The reaction mixture was stirred for 3 h at room temperature, hydrolyzed with saturated NH_4Cl (20 mL), and extracted with Et_2O (3 × 25 mL). The organic layer was separated and dried ($MgSO_4$). The crude product was purified by column chromatography (pentane/ether 90/10) to give **4d** (650 mg, 88% yield): ^{1}H NMR ($CDCl_3$) δ 5.98−5.72 (m, 4H), 5.31−4.90 (m, 8H), 4.16−3.90 (m, 4H), 3.50−3.30 (m, 2H), 2.33−2.00 (m, 4H), 1.74−1.42 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 138.8, 135.6, 116.8, 114.8, 79.4, 71.9, 30.3, 29.3; IR (neat, cm^{-1}) 3079, 2925, 1088, 994, 912; MS (DCI/NH_3) *m*/*z* $(MH)^+ = 251$, $(MNH_4^+) = 268$.

***dl*-1,1′-Bis(oxa-5-cycloheptadiene) (16a).** From **4d** (100 mg, 0.40 mmol) the bicycle **16a** was obtained (39 mg, 50% yield) following the general procedure: ^{1}H NMR ($CDCl_3$) δ 5.83−5.76 (m, 2H), 5.66−5.60 (m, 2H), 4.40 (dd, J = 1.1, 4.1 Hz, 2H), 4.07 (dd, J = 1.1, 4.7 Hz, 2H), 3.55−3.50 (m, 2H), 2.44−2.40 (m, 2H), 2.18−2.12 (m, 2H), 1.90−1.75 (m, 4H); ^{13}C NMR ($CDCl_3$) δ 131.5, 129.7, 83.8, 68.8, 30.4, 26.4; IR (neat, cm^{-1}) 3018, 2926, 1137; MS (DCI/NH_3) *m*/*z* $(MH)^+ = 195$, $(MNH_4^+) = 212$.

***cis*-4-Allyloxy-cyclopent-2-enol (17).** To a solution of *cis*-4-cyclopentene-1,3-diol (500 mg, 5 mmol) in dry THF (30 mL) at 0 °C was added NaH (210 mg, 5.25 mmol, 60% dispersion in mineral oil), and the reaction mixture was stirred at room temperature for 15 min. A solution of allyl bromide (0.46 mL, 5.25 mmol) in dry DMF (30 mL) was added dropwise, and the mixture was stirred at room temperature for 2 h. The reaction mixture was hydrolyzed with saturated NH_4Cl (25 mL), extracted with Et_2O (2 × 20 mL), and washed with saturated NaCl (3 × 10 mL). The organic layer was dried ($MgSO_4$). The crude product was purified by column chromatography (pentane/ether 90/10) to yield **17** (295 mg, 43% yield): ^{1}H NMR ($CDCl_3$) δ 5.98−5.80 (m, 3H), 5.22 (dd, J = 1.9, 15.2 Hz, 1H), 5.12 (dd, J = 1.1, 10.3 Hz, 1H), 4.55 (br s, 1H), 4.35−4.30 (m, 1H), 4.03−3.91 (m, 2H), 3.07 (br s, 1H), 2.65−2.55 (m, 1H), 1.58−1.50 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 137.4, 134.9, 133.7, 117.1, 81.5, 74.6, 69.9, 40.8; IR (neat, cm^{-1}) 3387, 1061, 992; MS (DCI/NH_3) *m*/*z* $(MH)^+ = 141$, $(MNH_4^+) = 158$.

***trans*-Benzoic Acid 4-Allyloxy-cyclopent-2-enyl Ester (18).** To a solution of **17** (55 mg, 3.96 mmol) in dry THF (30 mL) were added triphenylphosphine (2.1 g, 7.92 mmol), benzoic acid (970 mg, 7.92 mmol), and diethyl azodicarboxylate (1.25 mL, 7.92 mmol). The reaction mixture was stirred at room temperature for 2 h, and the solvent was removed under vacuum. The crude product was purified by column chromatography (pentane/ether 90/10) to yield **18** (920 mg, 95% yield): ^{1}H NMR ($CDCl_3$) δ 8.02−7.98 (m, 2H), 7.57−7.50 (m, 1H), 7.44−7.39 (m, 2H), 6.25−6.22 (m, 1H), 6.18−6.15 (m, 1H), 6.05−6.01 (m, 1H), 6.00−5.88 (m, 1H), 5.29 (dd, J = 1.3, 15.8 Hz, 1H), 5.19 (dd, J = 1.3, 10.2 Hz, 1H), 4.84−4.80 (m, 1H), 4.05−3.99 (m, 2H), 2.37−2.21 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 166.3, 137.6, 134.8, 133.5, 132.8, 129.5, 128.2, 117.0, 82.6, 79.4, 70.1, 37.7.

***trans*-4-Allyloxy-cyclopent-2-enol (19).** To a solution of **18** (1.17 g, 4.6 mmol) in MeOH (25 mL) was added NaOMe (3.5 mL, 5.3 mL in MeOH), and the reaction mixture was stirred at room temperature for 1 h. The mixture was treated with 1 N HCl to reach pH = 6 and was extracted with EtOAc (2 × 20 mL), dried ($MgSO_4$), and concentrated under vacuum. The crude product was purified by column chromatography (pentane/ether 50/50) to give **19** (550 mg, 85% yield): ^{1}H NMR ($CDCl_3$) δ 6.04−5.98 (m, 2H), 5.94−5.81 (m, 1H), 5.23 (dd, J = 1.0, 17.2 Hz, 1H), 5.14 (dd, J = 1.1, 10.3 Hz, 1H), 4.98−4.94 (m, 1H), 4.72−4.68 (m, 1H), 3.96−3.93 (m, 2H), 2.41 (br s, 1H), 2.16−2.08 (m, 1H), 1.97−1.88 (m, 1H); ^{13}C NMR ($CDCl_3$) δ 138.0, 134.7, 134.0, 116.9, 82.9, 75.3, 69.8, 40.5; IR (neat, cm^{-1}) 3381, 1357, 1062, 993, 927; MS (DCI/NH_3) *m*/*z* $(MH)^+ = 141$, $(MNH_4^+) = 158$.

***trans*-3,5-Bis-allyloxy-cyclopentene (9b).** To a solution of **19** (500 mg, 3.57 mmol) in dry THF (20 mL) at 0 °C was added NaH (215 mg, 5.35 mmol, 60% dispersion in mineral oil), and the mixture was stirred for 30 min at room temperature. Allyl bromide (0.46 mL, 5.35 mmol) in dry DMF (20 mL) was added, and the reaction was stirred for 6 h at room temperature. NaH (215 mg, 5.35 mmol) and allyl bromide (0.46 mL, 5.35 mmol) were added, and the mixture was heated to 50 °C for 3 h. The mixture was hydrolyzed with saturated NH_4Cl (20 mL), extracted with Et_2O (2 × 20 mL), and washed with saturated NaCl (3 × 10 mL). The organic layer was dried ($MgSO_4$). The crude product was purified by column chromatography (pentane/ether 70/30) to afford **9b** (490 mg, 77% yield): ^{1}H NMR ($CDCl_3$) δ 6.10−6.07 (m, 2H), 5.96−5.82 (m, 2H), 5.24 (dd, J = 2.8, 19.2 Hz, 2H), 5.14 (dd, J = 2.8, 8.8 Hz, 2H), 4.72−4.68 (m, 2H), 4.00−3.90 (m, 4H), 2.04 (dd, J = 6.6, 6.6 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 135.6, 135.0, 116.9, 83.0, 70.1, 38.0; IR (neat, cm^{-1}) 3080, 1075, 922; MS (DCI/NH_3) *m*/*z* $(MNH_4^+) = 198$.

Acknowledgment. The authors are thankful to Dr. Tracy J. Jenkins for proofreading this manuscript and to Alain Valleix for running mass spectra.

Supporting Information Available: ^{1}H and ^{13}C NMR spectra for compounds **2a**, **3a**, **4a**, **4a′**, **9a**, **9a′**, **9b**, **D**, **2b**, **3b**, **4b**, **10a**, **3c**, **4c**, **12a**, **12b**, **5c**, **15a**, **5a**, **6a**, **7a, 8a**, **11a**, **14a**, **5b**, **6b**, **13a**, **3d**, **4d**, **16a**, **17**, **18**, and **19**. This material is available free of charge via the Internet at http://pubs.acs.org.

JO982098U